

[0098] What is claimed is:

1. A method for making carbon-silica products comprising the steps of:  
providing plant matter comprising at least about 3 weight percent of silica, non-silica minerals and metals;  
contacting the plant matter with an aqueous solution of sulfuric acid having an acid concentration ranging from about 0.01 weight percent to about 30 weight percent to produce a mixture of plant matter and acid solution;  
reacting the mixture at a temperature ranging from about 10°C to about 250°C for a reaction period ranging from about six seconds to about 48 hours, thereby leaching minerals out of the plant matter to produce a carbon-silica product having an adjusted mole ratio of fixed carbon to silica of at least about 1.0:1; and  
thereafter removing the acid solution from the carbon-silica product.
2. The method of claim 1 wherein the plant matter is selected from the group consisting of naturally occurring plant matter, processed plant matter, and mixtures thereof.
3. The method of claim 2 wherein the plant matter is selected from the group consisting of rice hulls, rice straw and mixtures thereof.
4. The method of claim 3 wherein the plant matter is rice hulls.
5. The method of claim 1 wherein the particle size of the plant matter is reduced prior to contacting it with the aqueous acid solution.

6. The method of claim 5 wherein the plant matter has a particle size ranging from about 10 microns to about 1 mm.
7. The method of claim 6 wherein the plant matter has an average particle size of about 150 microns after being reduced in size.
8. The method of claim 1 wherein the mixture of plant matter and aqueous acid solution is mixed.
9. The method of claim 8 wherein the mixing is continuous.
10. The method of claim 1 wherein the solution of aqueous sulfuric acid is heated before contacting the plant matter.
11. The method of claim 1 wherein the mixture of plant matter and aqueous sulfuric acid is heated after contacting the plant matter.
12. The method of claim 1 wherein the mixture is reacted at a temperature less than 94°C.
13. The method of claim 1 wherein the mixture is reacted at a temperature of at least 94°C.
14. The method of claim 1 wherein the mixture is reacted at a temperature ranging from about 94°C to about 250°C.
15. The method of claim 14 wherein the mixture is reacted at a temperature ranging from about 94°C to about 105°C.

16. The method of claim 14 wherein the mixture is reacted at a temperature ranging from about 105°C to about 140°C.

17. The method of claim 14 wherein the mixture is reacted at a temperature ranging from about 140°C to about 160°C.

18. The method of claim 14 wherein the mixture is reacted at a temperature ranging from about 160°C to about 250°C.

19. The method of claim 1 wherein the plant matter comprises from less than 1 weight percent to more than about 35 weight percent of the mixture.

20. The method of claim 19 wherein the plant matter comprises from about 1 weight percent to about 30 weight percent of the mixture.

21. The method of claim 19 wherein the plant matter comprises from about 1 weight percent to about 10 weight percent of the mixture.

22. The method of claim 19 wherein the plant matter comprises from about 10 weight percent to about 30 weight percent of the mixture.

23. The method of claim 1 wherein the plant matter comprises about 10 weight percent of the mixture.

24. The method of claim 1 wherein the plant matter comprises about 25 weight percent of the mixture.

25. The method of claim 1 wherein the plant matter comprises about 29 weight percent of the mixture.

26. The method of claim 1 wherein the aqueous acid solution has an acid concentration ranging from about 0.06 weight percent to about 1 weight percent.

27. The method of claim 1 wherein the aqueous acid solution has an acid concentration ranging from about 1 weight percent to about 5 weight percent.

28. The method of claim 1 wherein the aqueous acid solution has an acid concentration ranging from about 5 weight percent to about 10 weight percent.

29. The method of claim 1 wherein the aqueous acid solution has an acid concentration ranging from about 10 weight percent to about 20 weight percent.

30. The method of claim 1 wherein the aqueous acid solution has an acid concentration ranging from about 20 weight percent to about 30 weight percent.

31. The method of claim 1 wherein the reaction period ranges from about 6 seconds up to 1 minute.

32. The method of claim 1 wherein the reaction period is greater than 1 minute and less than about 30 minutes.

33. The method of claim 1 wherein the reaction period is greater than 30 minutes and ranges up to 12 hours.

34. The method of claim 1 wherein the reaction period is greater than 12 hours and ranges up to about 48 hours.

35. The method of claim 1 wherein the carbon-silica product is washed and dried.

36. The method of claim 1 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio ranging from about 1.0:1 to about 5:1.

37. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 1.5:1.

38. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 2:1.

39. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 2.5:1.

40. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 3:1.

41. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 3.5:1.

42. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 4:1.

43. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 4.5:1.

44. The method of claim 36 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio of about 5:1.

45. The method of claim 1 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio less than about 5:1.

46. The method of claim 1 wherein the carbon-silica product has a fixed carbon-to-silica mole ratio greater than about 5:1.

47. The method of claim 1 wherein the carbon-silica product comprises less than about 1000 ppm by weight minerals.

48. The method of claim 47 wherein the carbon-silica product comprises less than about 500 ppm by weight minerals.

49. The method of claim 48 wherein the carbon-silica product comprises less than about 200 ppm by weight minerals.

50. The method of claim 49 wherein the carbon-silica product comprises less than about 100 ppm by weight minerals.

51. The method of claim 1 wherein the carbon-silica product comprises less than about 10 ppm by weight phosphorous.

52. The method of claim 51 wherein the carbon-silica product comprises less than about 4 ppm by weight phosphorous.

53. The method of claim 1 wherein the carbon-silica product comprises less than about 10 ppm by weight sodium.

54. The method of claim 1 wherein the carbon-silica product comprises less than about 10 ppm by weight potassium.

55. The method of claim 1 wherein the carbon-silica product comprises less than about 10 ppm by weight magnesium.

56. The method of claim 1 wherein the carbon-silica product comprises less than about 20 ppm by weight calcium.

57. The method of claim 56 wherein the carbon-silica product comprises less than about 10 ppm by weight calcium.

58. The method of claim 1 wherein the carbon-silica product comprises less than about 10 ppm by weight manganese.

59. The method of claim 1 wherein the carbon-silica product comprises less than about 30 ppm by weight iron.

60. The method of claim 59 wherein the carbon-silica product comprises less than about 20 ppm by weight iron.

61. The method of claim 60 wherein the carbon-silica product comprises less than about 10 ppm by weight iron.

62. The method of claim 1 wherein the carbon-silica product comprises less than about 5 ppm by weight boron.

63. The method of claim 62 wherein the carbon-silica product comprises less than about 2 ppm by weight boron.

64. The method of claim 63 wherein the carbon-silica product comprises less than about 1 ppm by weight boron.

65. The method of claim 1 wherein the carbon-silica product comprises less than about 50 ppm by weight aluminum.

66. The method of claim 65 wherein the carbon-silica product comprises less than about 20 ppm by weight aluminum.

67. The method of claim 1 wherein the carbon-silica product is pelletized.

68. The method of claim 1 wherein the carbon-silica product has an internal void volume of about 30% to about 90%.

69. The method of claim 68 wherein the carbon-silica product has an internal void volume of about 30% to about 80%.

70. The method of claim 1 wherein the carbon-silica product has an internal void volume greater than about 50%.

71. The method of claim 70 wherein the carbon-silica product has an internal void volume greater than about 75%.

72. The method of claim 1 wherein the mixture is reacted in a batch process.

73. The method of claim 1 wherein the mixture is reacted in a continuous process.

74. The method of claim 1 wherein the mixture is reacted in a plug flow process.

75. The method of claim 1 wherein a powder is made from the carbon-silica product.

76. The method of claim 75 wherein the powder is pelletized.



77. The method of claim 1 wherein the plant matter and acid solution are contacted in multiple stages.

78. The method of claim 1 comprising the step of devolatilizing the carbon-silica product.

79. The method of claim 75 comprising the step of devolatilizing the resultant powder.

80. The method of claim 79 comprising the step of pelletizing the devolatilized powder.

81. The method of claim 76 comprising the step of devolatilizing the pelletized powder.

82. The method of claim 78 wherein the devolatilization step is done by chemical devolatilization, thermal devolatilization, or a combination thereof.

83. The method of claim 79 wherein the devolatilization step is done by chemical devolatilization, thermal devolatilization, or a combination thereof.

84. The method of claim 81 wherein the devolatilization step is done by chemical devolatilization, thermal devolatilization, or a combination thereof.

85. The method of claim 1 wherein the carbon-silica product is further reacted in a carbothermal reactor at a temperature ranging from about 1250°C to about 2200°C to produce a silicon-containing product.

86. The method of claim 85 wherein the carbon-silica product is reacted in a carbothermal reactor at a temperature ranging from about 1300°C to about 1475°C to produce a silicon-containing product.

87. The method of claim 85 wherein the carbon-silica product is reacted in a carbothermal reactor at a temperature ranging from about 1475°C to about 1600°C to produce a silicon-containing product.

88. The method of claim 85 wherein the carbon-silica product is reacted in a carbothermal reactor at a temperature ranging from about 1600°C to about 2200°C to produce a silicon-containing product.

89. The method of claim 78 wherein the devolatilized carbon-silica product is further reacted in a carbothermal reactor at a temperature ranging from about 1250°C to about 2200°C to produce a silicon-containing product.

90. The method of claim 89 wherein the devolatilized carbon-silica product is reacted in a carbothermal reactor at a temperature ranging from about 1300°C to about 1475°C to produce a silicon-containing product.

91. The method of claim 89 wherein the devolatilized carbon-silica product is reacted in a carbothermal reactor at a temperature ranging from about 1475°C to about 1600°C to produce a silicon-containing product.

92. The method of claim 89 wherein the devolatilized carbon-silica product is reacted in a carbothermal reactor at a temperature ranging from about 1600°C to about 2200°C to produce a silicon-containing product.

93. The method of claim 85 wherein the carbothermal reactor is a static bed reactor.

94. The method of claim 85 wherein the carbothermal reactor is a moving bed reactor.

95. The method of claim 85 wherein the carbothermal reactor is a rotary tube reactor.

96. The method of claim 85 wherein the carbothermal reactor is a fluidized bed reactor.

97. The method of claim 85 wherein the carbothermal reactor is a furnace reactor that employs an external heat source.

98. The method of claim 85 wherein the carbothermal reactor is a flame reactor.

99. The method of claim 85 wherein the carbothermal reactor is a laser reactor.

100. The method of claim 85 wherein the carbothermal reactor is a plasma reactor.

101. The method of claim 85 wherein the carbothermal reactor comprises an atmosphere containing inert gas.

102. The method of claim 85 wherein the carbothermal reactor comprises an atmosphere containing nitrogen.

103. The method of claim 85 wherein the carbothermal reactor comprises an atmosphere containing nitrogen and hydrogen.

104. The method of claim 85 wherein the carbothermal reactor comprises an atmosphere containing nitrogen and ammonia.

105. The method of claim 85 wherein the carbothermal reactor comprises an atmosphere containing chlorine.

106. A carbon-silica product comprising a particulate powder, each particle of the powder further comprising fixed carbon and silica bound to each other on at least a micron scale without the use of a binding agent, the mole ratio of fixed carbon to silica in the powder being at least about 1.0:1.

107. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is from about 1.5:1 to about 5:1.

108. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 1.5:1.

109. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 2:1.

110. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 2.5:1.

111. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 3:1.

112. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 3.5:1.

113. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 4:1.

114. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 4.5:1.

115. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is about 5:1.

116. The carbon-silica product of claim 106 wherein the mole ratio of fixed carbon to silica is greater than 5:1.

117. The carbon-silica product of claim 106 wherein the powder is devolatilized.

118. The carbon-silica product of claim 106 wherein the powder is pelletized.

119. The carbon-silica product of claim 117 wherein the powder is pelletized.

120. The carbon-silica product of claim 118 wherein the pelletized powder is devolatilized.

121. The carbon-silica product of claim 106, made from plant matter.

122. The carbon-silica product of claim 121, made from the group consisting of rice hulls, rice straw, and mixtures thereof.

123. Silicon made from the powder of claim 106.

124. Silicon made from the devolatilized powder of claim 117.

125. Silicon made from the pelletized powder of claim 118.

126. Silicon carbide made from the powder of claim 106.

127. Silicon carbide made from the devolatilized powder of claim 117.

- 128. Silicon carbide made from the pelletized powder of claim 118.
- 129. Silicon nitride made from the powder of claim 106.
- 130. Silicon nitride made from the devolatilized powder of claim 117.
- 131. Silicon nitride made from the pelletized powder of claim 118.
- 132. Silicon tetrachloride made from the powder of claim 106.
- 133. Silicon tetrachloride made from the devolatilized powder of claim 117.
- 134. Silicon tetrachloride made from the pelletized powder of claim 118.
- 135. The carbon-silica product of claim 106 comprising less than about 1000 ppm by weight minerals.
- 136. The carbon-silica product of claim 135 comprising less than about 500 ppm by weight minerals.
- 137. The carbon-silica product of claim 136 comprising less than about 200 ppm by weight minerals.
- 138. The carbon-silica product of claim 137 comprising less than about 100 ppm by weight minerals.
- 139. The carbon-silica product of claim 135 wherein the minerals are selected from the group consisting of sodium, potassium, magnesium, calcium, manganese, iron, boron, aluminum, phosphorous, and oxygen-containing compounds thereof.

140. The carbon-silica product of claim 136 wherein the minerals are selected from the group consisting of sodium, potassium, magnesium, calcium, manganese, iron, boron, aluminum, phosphorous, and oxygen-containing compounds thereof.

141. The carbon-silica product of claim 137 wherein the minerals are selected from the group consisting of sodium, potassium, magnesium, calcium, manganese, iron, boron, aluminum, phosphorous, and oxygen-containing compounds thereof.

142. The carbon-silica product of claim 138 wherein the minerals are selected from the group consisting of sodium, potassium, magnesium, calcium, manganese, iron, boron, aluminum, phosphorous, and oxygen-containing compounds thereof.

143. The carbon-silica product of claim 106 comprising less than about 10 ppm by weight phosphorous.

144. The carbon-silica product of claim 143 comprising less than about 4 ppm by weight phosphorous.

145. The carbon-silica product of claim 106 comprising less than about 10 ppm by weight sodium.

146. The carbon-silica product of claim 106 comprising less than about 10 ppm by weight potassium.

147. The carbon-silica product of claim 106 comprising less than about 10 ppm by weight magnesium.



148. The carbon-silica product of claim 106 comprising less than about 20 ppm by weight calcium.

149. The carbon-silica product of claim 148 comprising less than about 10 ppm by weight calcium.

150. The carbon-silica product of claim 106 comprising less than about 10 ppm by weight manganese.

151. The carbon-silica product of claim 106 comprising less than about 30 ppm by weight iron.

152. The carbon-silica product of claim 151 comprising less than about 20 ppm by weight iron.

153. The carbon-silica product of claim 152 comprising less than about 10 ppm by weight iron.

154. The carbon-silica product of claim 106 comprising less than about 5 ppm by weight boron.

155. The carbon-silica product of claim 154 comprising less than about 2 ppm by weight boron.

156. The carbon-silica product of claim 106 comprising less than about 50 ppm by weight aluminum.

157. The carbon-silica product of claim 156 comprising less than about 20 ppm aluminum.

158. The carbon-silica product of claim 106 having an internal void volume of about 30% to about 90%.

159. The carbon-silica product of claim 158 having an internal void volume of about 30% to about 80%.

160. The carbon-silica product of claim 106 having an internal void volume greater than about 50%.